

# On Low-Level Thermodynamic Parameters Associated with Tornadoic and Nontornadoic Supercells

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## 1. Introduction

From recent work by several researchers, it appears that low-level thermodynamic factors are important regarding development of supercell tornadoes. In particular, lifting condensation level (LCL) heights and surface dewpoint depressions suggesting large boundary-layer humidity have been shown to be associated with tornadoic supercells (Rasmussen and Blanchard 1998, hereafter "RB98") and linked to favorable rear flank downdraft characteristics (Markowski et al. 2002). But operationally, little attention has been given to other low-level thermodynamic parameters such as convective inhibition (CIN) and level of free convection (LFC) heights in tornadoic and nontornadoic supercell cases.

RB98 found that tornadoic supercell environments tended to have less CIN than those associated with nontornadoic supercells. Also, in simulations involving moderate vertical shear and small to moderate convective available potential energy (CAPE), McCaul and Cohen (2000) and McCaul and Weisman (2001) found that updraft intensity tended to increase when LFC heights were generally lower (between 1.5 and 3.0 km AGL) and buoyancy was increased in low-levels. These results suggest that parameters impacting low-level buoyancy, such as *CIN*, *LFC height*, and *low-level CAPE* (see Fig. 1, reverse-highlighted parameters) may also have relevance regarding tornadoic supercell environments. This paper will examine these three parameters using a database of model profiles associated with both tornadoic and nontornadoic supercells.

## 2. Methodology

### a. Database

Thompson and Edwards (2000a) have shown Rapid Update Cycle (RUC) profiles to be helpful and timely for estimating and evaluating environments near supercells when actual soundings are not available. The database examined in this study consists of 321 RUC-2 analysis and short-term forecast soundings from 1999, 2000, and 2001 associated with tornadoic and nontornadoic supercells (see Table 1). Supercells were identified as in Thompson and Edwards (2000b), with 146 profiles obtained with permission from their RUC-2 database begun in the same study. The other 175 soundings were accumulated independently during 2001. In general, the nearest available RUC-2 grid point in the inflow sector of the supercell was used, within an hour prior to or during the event. Actual observations from nearby surface reporting stations were used to update and modify the

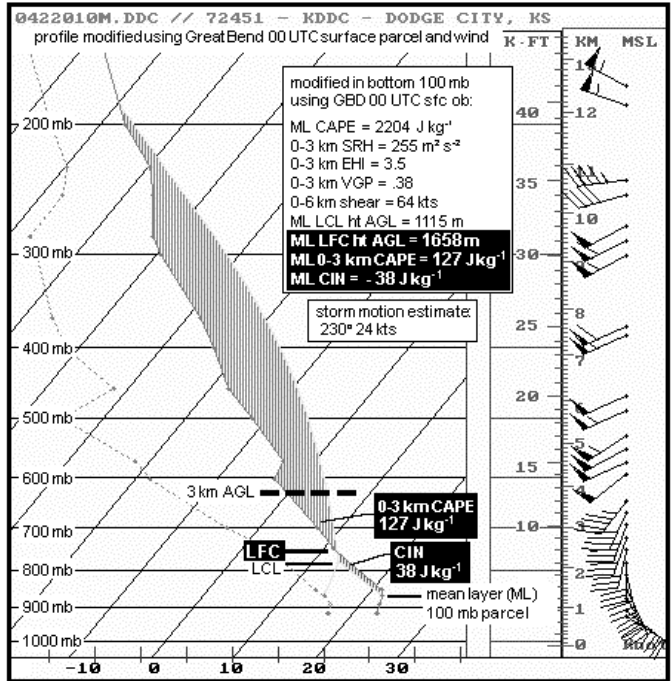


Figure 1. SkewT logp diagram of Dodge City, Kansas observed sounding at 00 UTC 4/22/01, modified in bottom 100 mb by Great Bend 00 UTC surface observation. A supercell that later produced the F4 Hoisington tornado was in progress north of Dodge City and west of Great Bend at this time.

boundary layer for these profiles to provide better accuracy (Thompson and Edwards 2000a).

The following method was used to modify the bottom 100-150 mb of the RUC-2 profiles using actual surface observations:

- 1) If the observed surface temperature was cooler than the model profile, the profile was interpolated in the bottom 50 mb.
- 2) If the observed surface temperature was warmer or the dew point more moist than the model profile, the bottom 100-150 mb was warmed using

**Table 1: RUC-2 profile database** (random supercell events 1999-2001)

Inclusion criteria: profile located at nearest surface reporting site in inflow air mass during or within 1 hour prior to supercell event; supercells radar-indicated (Thompson & Edwards 2000b).

supercell profiles	nontornadoic	F0-F1 weak tornadoic	F2-F5 significant tornadoic
321*	155	83	83

\*146 profiles from RUC-2 database begun by Thompson & Edwards (2000b).

Table 1. Description of RUC-2 profile database used in this study.

interpolation and a depth that would allow a surface parcel to have some CIN with the LFC above the LCL.

- 3) If the observed surface dew point was warmer than the model profile, the moisture profile in the bottom 100 mb was increased accordingly using interpolation.

After working with a variety of profile shapes and environments, this method seemed workable and reasonably realistic in correcting unlikely or unphysical low-level thermodynamic patterns (e.g., LFC below LCL, or LFC on the ground) that resulted when observed surface observations were warmer or more moist than model-derived boundary layer data.

#### b. Computations

For thermodynamic comparisons, Doswell and Rasmussen (1994) suggested using the most unstable parcel in the bottom 300 mb. But Markowski et al. (2002) suggested that surface-based or near-surface parcels are most relevant for assessing CAPE and CIN regarding supercell tornado potential. As “near-surface” parcels for this study, thermodynamic parameters were computed using the *most unstable* of three lifted parcel choices from the *bottom 100 mb*:

- (i) A surface parcel.
- (ii) A mixed parcel from the bottom 50 mb.
- (iii) A mixed parcel from the bottom 100 mb.

Because the virtual temperature correction (Doswell and Rasmussen 1994) is not used in many operational sounding analysis software applications, and resulting sounding analysis examples without the correction are visually more straightforward, results in this short paper will be presented without this correction.

### 3. Results

#### a. Convective inhibition (CIN)

It should be noted that convection was ongoing for storm cases in this study, and that CIN in this context was used to suggest the degree of stable layer near the ground, rather than as a guideline related to potential for convective initiation.

Figure 2 shows the distributions of CIN for nontornadic, weak tornadic, and significant tornadic supercell cases from the RUC-2 database. Box and whiskers graph distributions similar to RB98 are used, where the hatched boxes contain the middle 50% of the events, and the median is a horizontal black bar. The vertical bars contain the middle 80% of the events. There is a signal suggesting that CIN associated with tornadic supercell cases tends to be lower than for nontornadic supercell cases, similar to results in RB98. This in turn suggests that large low-level negative buoyancy in the general environment works against tornado development.

As noted in RB98, supercells occurring with large CIN are suggestive of “elevated” storms (Colman 1990) that are thought to be less likely to produce tornadoes. Numerical simulations by Leslie and Smith (1978) suggested that strong low-level stability (e.g., large CIN) works against generation of intense surface vorticity.

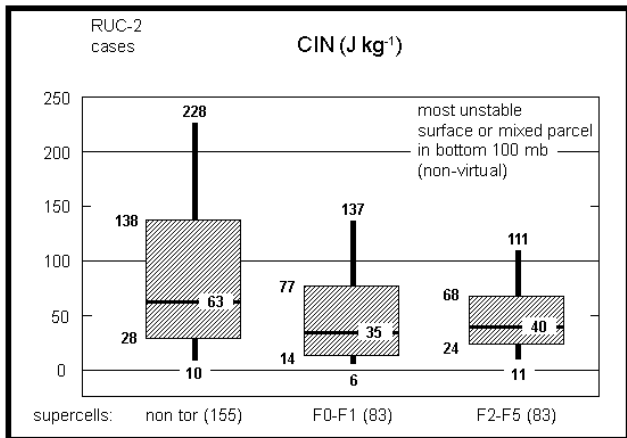


Figure 2. Box and whiskers graphs of CIN ( $\text{J kg}^{-1}$ ) for RUC-2 supercell cases, computed as described in text. Cases are grouped as significant tornadoes (“F2-F5”; right), weak tornadoes (“F0-F1”; middle), and nontornadic (“non tor”; left). Hatched boxes denote 25<sup>th</sup> to 75<sup>th</sup> percentiles, with horizontal bar showing median value. Vertical bars above and below boxes extend to the 10<sup>th</sup> and 90<sup>th</sup> percentiles.

From this study, it appears that supercells persisting in environments with near-surface CIN larger than roughly  $150\text{--}200 \text{ J kg}^{-1}$  extending through the bottom 2-3 km are least likely to produce significant tornadoes, probably because such storms are notably “elevated” and working with a relatively deep low-level stable layer. Most supercells producing significant tornadoes are associated with near-surface CIN values less than  $50\text{--}100 \text{ J kg}^{-1}$ .

#### b. LFC height

Figure 3 shows distributions of LFC heights for the RUC-2 database, suggesting that supercell tornado events tend to be associated with lower LFC heights. Lower LFC heights above ground imply more CAPE in low-levels, which may also imply potential for increased low-level accelerations. The majority of tornadic supercells are associated with LFC heights below 2000-2200 m.

#### c. Low-level CAPE

Figure 4 shows distributions of 0-3 km CAPE ( $\text{CAPE}_{0-3}$ ) for the RUC-2 database. Although there is a

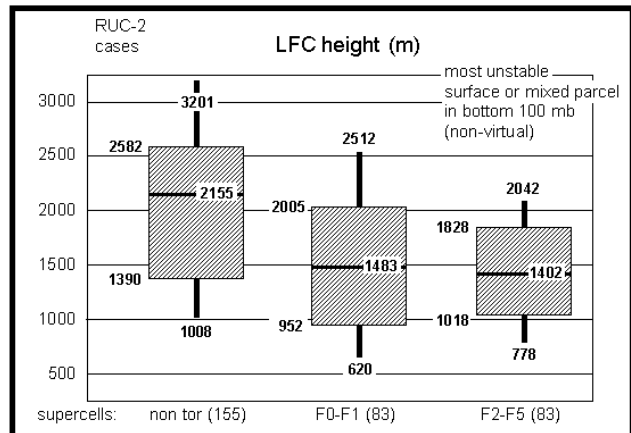


Figure 3. As in Fig. 2, except LFC height above ground (m).

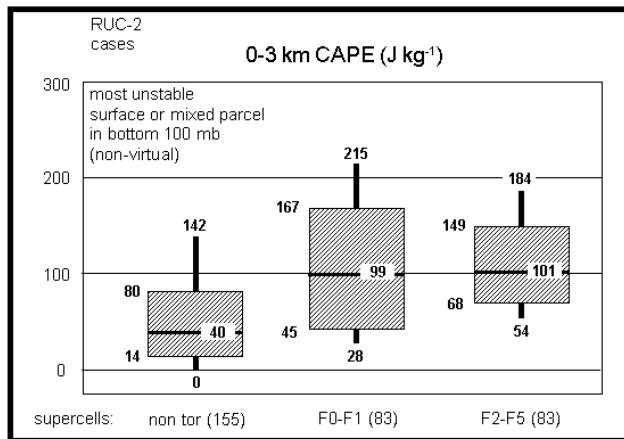


Figure 4. As in Fig. 2, except CAPE below 3 km AGL ( $\text{J kg}^{-1}$ ).

fairly wide degree of scatter in the weak tornado cases, it can be seen that the profiles associated with supercell tornadoes tend to have more low-level CAPE than those associated with nontornadic supercell events. As with lower LFC heights, more CAPE located closer to the ground may suggest potential for significant low-level parcel accelerations and possibly increased low-level stretching.

Thompson et al. (2002, this volume) found less separation in  $\text{CAPE}_{0-3}$  values between tornadic and nontornadic supercell cases when using a larger database of RUC-2 profiles. They did not update or modify profiles using actual surface observations, and used a different lifted parcel methodology than this examination, both of which would affect comparisons between the two studies. However, the difference in results may also highlight the sensitivity of low-level CAPE computations to boundary-layer conditions and lifted parcel used, suggesting caution in using such a parameter operationally. Additionally, the wide range of  $\text{CAPE}_{0-3}$  values associated with tornadic supercells (ranging from less than  $50 \text{ J kg}^{-1}$  to more than  $200 \text{ J kg}^{-1}$  in the RUC-2 database) appears to offer limited discrimination value when using this parameter apart from other low-level thermodynamic measures.

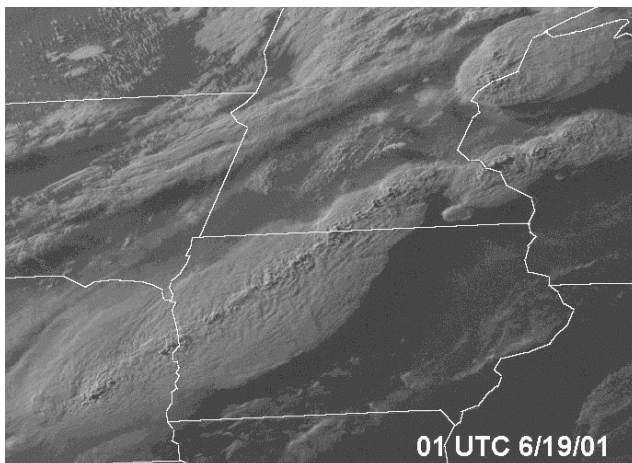


Figure 5. Visible satellite photo at 01 UTC 6/19/01 showing storms ahead of a cold front from Minnesota to Nebraska.

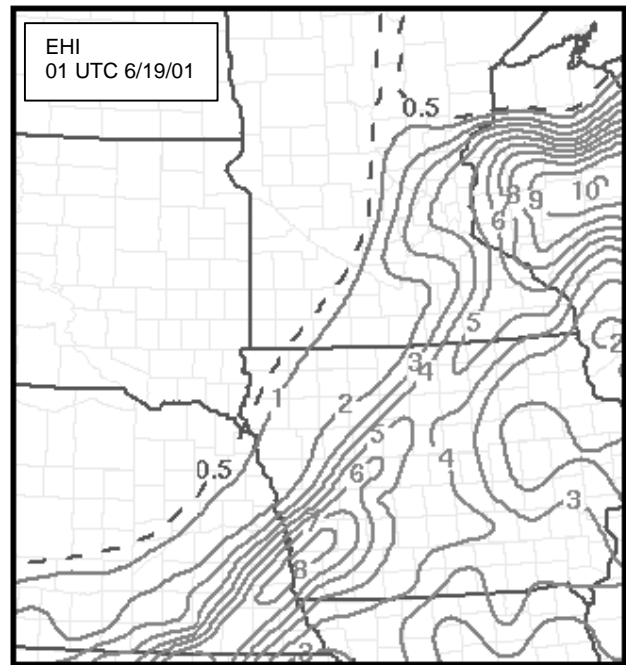


Figure 6. Depiction of 0-3 km EHI at 01 UTC 6/19/01 from Storm Prediction Center (SPC) mesoanalysis page. Courtesy John Hart and SPC.

#### 4. Potential operational use

A look at an event involving thunderstorms and supercells over a large area suggests how low-level thermodynamic parameters from this study might add useful information to accepted shear-CAPE methods in highlighting awareness of increased *potential* for supercell tornadoes.

After 00 UTC on 19 June 2001, scattered thunderstorms (including several supercells) were located over parts of Minnesota, Wisconsin, Iowa and Nebraska ahead of a cold front (Fig. 5). The only significant tornado occurred with a long-lived supercell in northwest Wisconsin (Fig. 7) where 3 people were killed. Figure 6 shows 0-3 km energy-helicity index (EHI, Davies 1993) and Fig. 7 shows LFC heights, both fields generated at the Storm Prediction Center (SPC) using RUC-2 profiles merged with early evening surface observations. EHI was large from Kansas to Wisconsin, suggesting good potential for storm rotation over a broad area of several states. But lower LFC heights ( $< 2000\text{--}2200 \text{ m}$ ) were found mainly in east central Minnesota and northwest Wisconsin. In this case, the lower LFC heights (implying less CIN and more low-level CAPE) appeared to help highlight the general area where a significant long track tornadic supercell occurred in the vicinity of an east-west surface boundary over northwest Wisconsin.

#### 5. Discussion

The data examined in this study reinforce the idea that low-level thermodynamic factors are important and related in some way to supercell tornado production when adequate wind shear and total CAPE are also present.

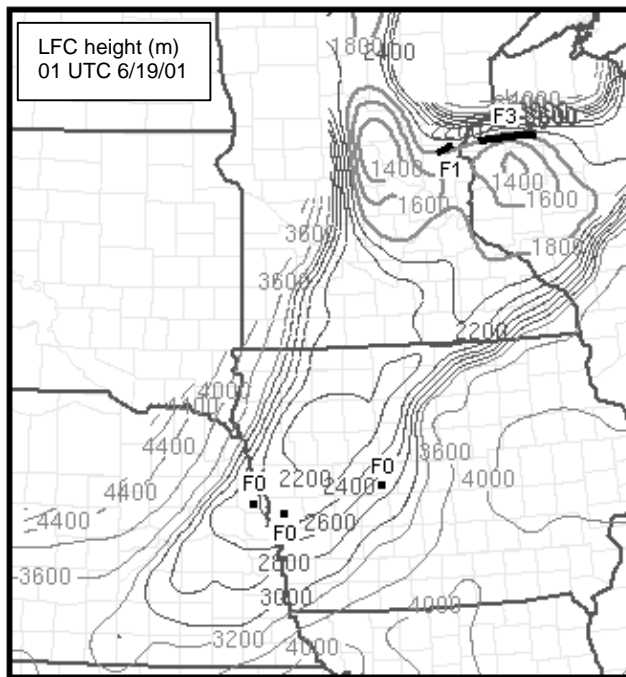


Figure 7. As in Fig. 6, except LFC height (m). Tornado locations and tracks are marked and labeled by intensity.

Perhaps parameters such as CIN, LFC, and low-level CAPE will be most useful in detecting supercell storm environments that are significantly “elevated” with a large stable layer near the ground. Significant tornadoes are less likely to occur in such settings (see RB98). Such cases can have *favorably low* LCL heights, but will also have *relatively high* LFC heights and large near-surface CIN. **A low LCL does not necessarily imply a low LFC.**

In his definition of “elevated” storms, Colman (1990) included only those storms located on the cool side of surface fronts or boundaries. Figure 8 suggests a different kind of “elevated” storm environment – one located *in the warm sector* south of a surface front, with an elevated mixed layer inversion creating the deep stable layer. In the Fig. 8 case, a supercell storm developed west of this “capped” environment, but continued eastward as an intense storm persisting for several hours through an area with large near-surface CIN ( $> 200 \text{ J kg}^{-1}$ ). The supercell did not produce any tornadoes, although several tornado warnings were issued based on radar.

Compare Fig. 8 with Fig. 1 earlier that showed the environment associated with a supercell on the following evening that produced the Hoisington F4 tornado. Although the shear-CAPE environments were impressive for both profiles, notice that in Fig. 1 the LFC was more than 1 km *lower*, and that CIN was *much less* ( $< 50 \text{ J kg}^{-1}$ ).

Because supercells in “elevated” environments unlikely to support tornadoes are relatively common, and such environments are not always readily apparent from the synoptic setting (e.g., the case in Fig. 8), examination of low-level thermodynamic fields such as LFC height and near-surface CIN can be useful in detecting such settings. Of 57 supercell cases from the RUC-2 database in this study with LFC height  $> 2200 \text{ m}$  and CIN  $> 125 \text{ J kg}^{-1}$ , only 2 cases (4%) were associated with significant

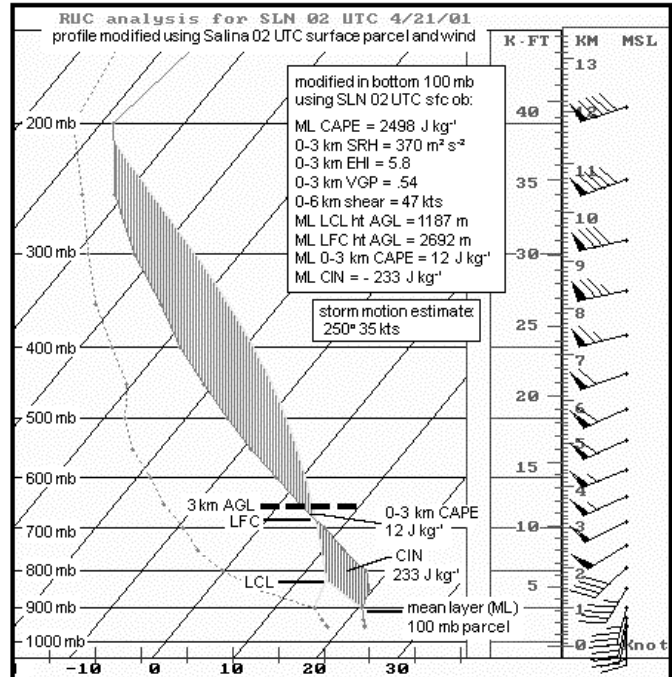


Figure 8. As in Fig. 1, except RUC-2 analysis profile for Salina, Kansas at 02 UTC 4/21/01, modified in the bottom 100 mb using Salina 02 UTC surface observation. This warm sector “elevated” profile was associated with a long-lived nontornadic supercell.

tornadoes, while 48 cases (84%) were associated with no tornadoes at all.

However, it should be emphasized that *ongoing* tornadic supercells in an environment with favorable shear-CAPE and low-level thermodynamic characteristics can later move into and persist in an environment with larger CIN (e.g., movement deeper into cool air north of a stationary boundary). In such cases, tornadoes with a strong mesocyclone may continue to occur for a time before the storm becomes significantly “elevated”.

Further research is planned regarding detectable low-level thermodynamic characteristics in combination with established parameters assessing wind shear and CAPE in tornado forecast situations.

## 6. Acknowledgements

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## 7. Key references

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